



# Environmental sustainability assessment tools for low carbon and climate resilient low income housing settlements

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## ABSTRACT

Reduction of greenhouse gases (GHG) emissions throughout the building lifecycle and climate vulnerability have recently become important environmental concerns in the development of low income housing. To address these concerns, several sustainability assessment tools have been developed to evaluate new development at urban scale. To evaluate the effectiveness of such tools in addressing greenhouse gas emission reduction and disaster resilience for low income housing schemes, five rating tools that are widely applied for assessing environmental sustainability of urban projects, namely, BREEAM-Community, LEED-ND, CASBEE-UD, SBTool2012, and GBI for Township, were reviewed. The analysis shows that both issues are addressed in the five rating tools for urban development, however aspects of disaster resilience are considered less and not comprehensive. Improvements to GHG emission reduction and disaster resilience, assessment methods, financial consideration, and assessment purposes have been suggested. These improvements can contribute to the development of low income settlements that emit low emissions and are resilient to natural disasters.

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## 1. Introduction

Housing the urban poor is a great challenge for low and middle income countries. During 1990–2000, 750 million people in developing countries were estimated to earn less than \$2 per day [1] and about 862 million people, a third of the world urban population, were reported to still live in slums in 2012, despite attempts to reduce the number of the urban poor under the Millennium Development Goal [2]. Several low cost housing programs have been implemented to provide accommodations for this socially disadvantaged group in cities. During the period 2000–2010, the slum upgrading programs claim to have assisted almost 220 million people in the slum communities [3], indicating the importance of housing programs, and this trend is expected to grow in the coming decades.

Since the mid-1990s, environmental sustainability in low cost housing has been emphasized [4] in correspondence with the promotion of sustainable human settlement development, as announced in the Istanbul Habitat Agenda II in 1995 [5]. Considering the significant numbers of housing in this segment, highly degraded environmental quality and inefficient resource exploitation can be expected if housing design is not environmentally sound. Therefore, green construction practices have been promoted and implemented, particularly in the developed countries, resulting in healthier living environment for low income families [6]. With growing concerns on the negative impacts of climate change and natural resource depletion, environmental issues including energy, water use efficiency and waste management have gained more recognition as important strategies for achieving sustainability in low cost housing as well [7]. The urban poor are viewed as the most vulnerable population to climate threats [8], and they are associated with sub-standard housings with low level of disaster resistance due to location of such housings often in the risky areas [9–11]. Therefore, improving housing conditions and infrastructure are key measures to help low income households to better cope with either everyday or catastrophic disasters [12]. The reduction of greenhouse gases emissions considering the building lifecycle and climate vulnerability thus has recently become major environmental concern in the development of low income housing with the aim to achieving sustainability [3]. With a vast number of housing that must be built or upgraded in the near future to meet MDG7, Target 11 on improving the lives of 100 million slum dwellers by 2020, this will be a great opportunity to increase the urban poor's wellbeing and avoid serious damages to their assets due to weather related disasters by building low carbon and climate resilient low income housing settlements.

To ensure that GHG emission reduction and disaster resilience are taken into account in the housing design for the urban poor, it is necessary that architects, planners, and developers have tools to evaluate the environmental performances of housing systems during design and planning process. Though several assessment tools have been developed to measure the sustainability of urban development projects [13–17], however, there is lack of critical

evaluation of the effectiveness of such tools in addressing the reduction of greenhouse gas emissions and climate vulnerability, and the evaluation of the applicability of such tools to low income housing, particularly in developing countries. The major objective of this article is, therefore, to review the sustainability assessment tools for urban development focusing on two aspects of GHG emission reduction and disaster resilience, and the application of such tools to assess low income housing. Specifically, this study aims, (a) to evaluate to what extent existing tools consider GHG emission reduction and disaster resilience; (b) to evaluate the application of the tools to assess GHG emission reduction and disaster resilience of low income housing by identifying their limitations in terms of comprehensiveness, assessment methods, and financial aspects and community participation; and (c) to identify and propose improvements required to enhance the effectiveness and the applicability of the assessment tools to low income housing. With improvements, a more comprehensive approach to evaluate existing settlements or new projects can be achieved, contributing to optimum solutions that integrate the principles of low carbon and climate resilient community to the development of low income housing. The paper consists of five sections: the first section provides an overview of the trend in low income housing growth in developing countries and the promotion of environmental sustainability in low income housing. Section 2 provides general background of low cost housing in developing countries, namely, definitions of various terms, types of housing and environmental issues related to energy use and climate risks. The next section reviews the sustainability assessment tools for urban neighborhood development, in terms of the coverage of GHG emission reduction and disaster resilience, assessment methods, and the consideration of financial aspect and community participation. Section 4 discusses strengths and weaknesses of the existing tools for the application to low income housing in developing countries. Then, the inclusion of key aspects needed to be incorporated in the assessment framework for low carbon and climate resilient low income housing is suggested before leading to concluding remarks.

## 2. Low income housing, energy issues and climate risk: a review

In developing countries, both formal and informal sector play the key role in housing provision [18]. This study focuses only on the formal mode of housing provision since formal housing providers have more potential in employing the assessment tools. Low income housing is known in various terms, including public housing, social housing, affordable housing, and community based housing. Each term refers to different actors involved in housing development and was coined in accordance with housing policies that evolved in the last 50–60 years. Housing policies have experienced major shifts in three periods – the first period in 1960s began with the public housing approach, the second period

Nomenclature		kWh	kilowatt hour
m	meter	Pa	Pascal
$m^2$	square meter	ach	air changes per hour
$m^3$	cubic meter	GHG	Greenhouse gas emissions
$m/s$	meter per second	LAI	Leaf Area Index
ha	hectare	SRI	Solar Reflectance Index
		DF	Daylight factor

in the mid-1970s when self-help approach was established and the third period in the mid-1980s, with the enabling approach [4,19]. Public housing is usually owned and managed by government agencies which are responsible for delivering housing consisting of accommodations, basic infrastructure, and facilities. Inability to meet high low income housing demand and unaffordability among the poor due to the high price of a housing unit were the main constraints of the first approach [18,19]. Moreover, in many developing countries, public housing approach happened in the age of modernization or city beautification, and therefore sometimes brought conflicts against governments from the urban poor as it justified the clearance of informal settlements [20]. Accordingly, a shift in housing policies towards self-help approach was introduced, which were less dependent on governmental agencies and provided opportunities for the poor to build or improve their own houses. Non-profit organizations usually took a leading role in supporting low income communities, who collaborated with local authorities to develop housing [18]. Self-help programs can be classified into three main types: site-service, site upgrading, and incremental development [21]. Compared with the conventional approach of public housing in which complete housing units are provided, this alternative approach focused on incremental development over a period of several years. The share of each type varied across regions with the highest amount of loans for sites-services projects was in the Middle-East and slum upgrading in Latin America (see Table 1).

Due to little impact on the supply of low income housing and cost-ineffectiveness of site-services approach, the concept of enabling environment has been promoted with private market mechanism [18,19]. Considering the limited resources and capacity of public agencies, this approach emphasizes the active role of private sector in the investment of low income housing market and the enabling role of governments in increasing the involvement of private sector [18]. Enabling policy for housing has been promoted and adopted by many governments around the world with different degrees of success [23]. In developing countries, private market for low income group is dominated by small scale developers or contractors whose financial capacity is quite limited [18].

The issue of environmental concerns and climate vulnerability in low income households has caught attention in response to a

growing concern about resource depletion and adverse impacts of climate change [5,24]. The mostly common concerns identified in the literature are as follows:

### 2.1. High energy use in transportation due to remote settlement areas

Acquiring convenient and accessible sites is the major challenge for low income housing development [4,25]. In the high-medium density areas, it is difficult to find lands at affordable price in spite of the availability of vacant lands owned by public or private owners [21]. Therefore, unserviced lands at the outskirt of cities or the peri-urban areas are often selected as a site for low income housing [26,27], in particular for sites-services and slum upgrading programs [28]. This creates unsustainable development pattern of urban sprawl. Based on theoretical background and empirical studies, it is well recognized that sparse development contributes to higher energy consumption and greenhouse gases emissions from transport sector [29–33]. These remote lands are mostly underdeveloped lacking basic infrastructure and everyday facilities nearby. The situation is aggravated when public transportation services are inaccessible in close proximity, resulting in limited mobility and the need for more time to travel. A comparative study of two low cost housings in Chennai, India shows that low income residents who live in the periphery are more dependent on motorized travel modes and spend higher travel cost for commuting than those who live in the central business center where the employments are mostly located [34]. Not only greater cost of travel, but higher transport energy consumption for daily trips can also be expected.

### 2.2. High energy expenditure due to lack of modern energy services or inefficient use of energy

Energy affordability is one of the main energy issues in low income housing across countries. Solving energy poverty has been prioritized to assist low income households in developed countries, as shown by the extensive body of research in energy efficiency in social housing e.g., [35–40]. With improved energy performance, low income households are likely to pay less for energy use especially for space heating and have more thermal comfort. Poverty reduction and increased quality of life are realized as the co-benefits of the application of low carbon technologies [41]. In developing countries, evidences show that urban low income households suffer from high energy cost relative to household income [1,42]. Several factors contribute to high energy cost. Due to lack of the provision of electricity services, illegal electricity connections are found in many informal settlements located in unauthorized lands or even in self-help housing where infrastructure services have not been expanded [42–47]. In addition, energy inefficient buildings and appliances were considered to be one of the main reasons for high energy cost [42]. Despite few empirical studies available, reduced electricity costs among low income households living in formal housing confirms the positive impacts of energy efficiency programs as presented in Table 2. These four

**Table 1**  
Regional breakdown of World Bank shelter loans during 1992–2005, in 2001 US\$ millions.  
Source: Adapted from Buckley and Kalarickal [22].

Region	Sites & services		Slum upgrading	
	US\$ millions	%	US\$ millions	%
Sub-Saharan Africa	16.32	3.23	42.42	12.54
East Asia and Pacific	35.8	7.08	40.78	12.05
Europe & Central Asia	16.46	3.25	10.61	3.14
Latin America & Caribbean	0	0.00	128.97	38.11
Middle East & North Africa	358.26	70.82	94.42	27.90
South Asia	79	15.62	21.18	6.26

**Table 2**

Summary of energy savings in urban low income housing in developing countries.

Location	Merida Housing <sup>a</sup>	Mangueira Project <sup>b</sup>	Baan Mankong <sup>c</sup>	Eur Ar Thorn <sup>d</sup>
Climate zone	The city of Merida, Mexico	Rio de Janeiro city, Brazil	Various cities, Thailand	Bangkok, Thailand
Housing type	Warm-humid	Humid	Hot-humid	Hot-humid
Building type	Social housing	Social housing	Self-help	Public housing
Number of residential units	2 Story detached house	4 Story flat	1–3 Story house	2 Story house
Average residential area (m <sup>2</sup> /unit)	1903	496	1103	5 Story flat
Density (units/ha)	100	37	N/A	3768
	30.69	N/A	263.3	73
N/A			N/A	N/A
Measures				
1. Slum upgrading				
Electricity saving			5%	
2. Efficient refrigerators (kWh/year)	1395	285.6		
Electricity saving	23%	67%		
3. Efficient lighting lamp (kWh/year)	171	53.52		
Electricity saving	80%	75%	43%	
4. Use of reflective glass (kWh/year)				9
Electricity saving relative to total consumption				0.17%
Passive design (kWh/year)				459
Electricity saving relative to total consumption				8.80%
				803
				0.40%
				1530
				0.70%

<sup>a</sup> Ceron-Palma et al. [48].<sup>b</sup> Bodach and Hamhaber [49].<sup>c</sup> Puapongsakorn et al. [50], CODI (2005).<sup>d</sup> Gonzales et al. [51].

housing projects show that the introduction of energy efficient appliances and technological measures were able to reduce household electricity consumption. However, these measures require high upfront costs. In contrast, significant amount of electricity could be saved through low or no cost measure like passive design, but thoughtful planning is required in the initial stage of housing development.

### 2.3. Poor solid waste management

Usually, local authority such as the municipality is responsible for collecting household solid waste. Due to the rapid growth of population and urbanization, municipal services tend to not be able to keep pace with the rising amount of waste. Inadequate and infrequent waste collection is often experienced by low income households in Asia due to inadequate collection fee. A study of 11 major Asian cities shows that the collection area coverage in a city can be as low as 50% and the frequency can range from twice a day for the wealthy neighborhoods to twice a week for the poor neighborhoods [52]. Especially in the urban periphery where many low income housing are located, waste collection service is likely to be absent or infrequent as a result of inadequate means of transport. In developing countries where the capacity and resources of municipalities are frequently limited, community participation in waste management is essential [53]. The effort of the community can be taken in several ways to reduce the quantity of wastes needed to be transported for disposal later. In an urban context, the community can take a role in early segregation, collecting waste to transfer station, recycling, and composting [53].

### 2.4. Inefficient use of resources for house construction and improvement

Limited budget of low income households is the major consideration for choosing building materials for house construction. The use of low cost materials with poor energy performance is prevalent particularly in self-help housing schemes. For example, corrugated metal or fiber cement roof tiles without insulation dominate in *Baan ManKong* projects in Thailand. In addition, in-situ construction is often selected due to ease of construction and low requirement of sophisticated machines and equipment. [54].

Compared with the prefabrication system, inefficient use of building materials and high amount of construction waste is more prevalent in in-situ systems. Waste in loss, poor use of construction materials, and inadequacies of design of self-help housing in Mexico not only lead to longer construction time but also increased construction costs [55]. Accordingly, improvement in the selection process of building materials and construction methods is required to efficiently use the already limited resources and to reduce life cycle cost during construction and post-occupancy periods of low income housing development.

### 2.5. Lack of open and green spaces

A minimal provision of open and green spaces is the common characteristic found in a concentrated urban setting. The small proportion of open and green spaces is even more critical in urban self-help housing exemplified by low percentage of green area in urban low income housing in Asian cities. The average green area of 0.5–1 m<sup>2</sup> is indicated for 40–80 m<sup>2</sup> land plots size in *Baan ManKong* project in Bangkok, accounting for 15–10% of the total site area when roads are included [56]. Likewise, 15% of the land of low income housing in Ho Chi Minh City, Vietnam is devoted to open space [57]. High density and high site coverage is increasingly acceptable for low cost housing due to the difficulty in acquiring adequate land for a large number of low income households. This notion is legally supported by building regulation specifically issued for low income housing in some countries (e.g., Thailand, Kenya) to allow higher site coverage in order to better facilitate the access of the poor to the land. According to the Thai Ministerial Regulation B.E. 2554 [58], government's low income housing projects in Thailand are allowed to have the setback less than the minimum distances required in the Ministerial Regulation No. 55 (B.E. 2543) by virtue of Building Control Act B.E.2522 (A.D.1979). Similarly, building code in Kenya has been revised since 2008 with the aim to develop the new building code that is suitable for the country's climatic conditions and modern technology. To reduce land and construction costs, the reduction of setback and gross floor area as the minimum house size for low income settlements will be permitted in the new code [59]. However, high percentage of built area potentially leads to negative environmental impacts in terms of poor ventilation, low

exposure to natural light, and higher risk to urban floods as a result of the absence of permeable surface to absorb water. To optimize the benefits for low income households the physical constraints, these environmental concerns should thus be incorporated during the housing design process.

### 2.6. Risk of natural disasters

Several self-help housings are located in the risky areas prone to natural disasters. For example, many inner-city *kampongs* including both formal and informal low income settlements in Jakarta, Indonesia are situated on areas that are exposure to floods [60]. Likewise, a number of *barangays* in Manila are affected by both earthquakes and floods, leading to the redevelopment of some *barangays* to be resilient to natural disasters [61]. With poor infrastructure and housing quality, the urban poor are highly vulnerable to natural disasters as they have low capacity to cope with and recover from natural disasters. The provision of basic infrastructure and durable dwellings has assisted low income households to suffer less losses and damages from flooding [62]. Considering climate risks and disasters that are potentially more intense and frequent due to climate change, it is important to integrate disaster resilience in the development of low income housing schemes.

As discussed above, environmental issues found in low income housing significantly are associated with housing location and the selection of building materials and construction techniques. To enhance environmental savings and disaster risk reduction, better decision on site selection, housing layout and dwelling design during the initial stage of housing development is important. This highlights the need for environmental sustainability assessment that can be used as a decision aid tool for evaluating housing projects against a set of indicators, resulting in careful housing planning and design that potentially minimize adverse effects on the environment and livelihood of the urban poor.

## 3. Sustainability assessment tools for urban development

With growing recognition that both building and its broader context play a great role in sustainability, indicator-based tools have been developed to address environmental sustainability from building scale to a larger scale of urban development [13,14]. Not only measuring the sustainability level, these tools can be used to guide urban projects including housing. There are nearly 20 tools available [15], and this paper focuses on those internationally accepted and have open-source access namely, BREEAM-Community, LEED for Neighborhood Developments (LEED-ND), CASBEE-Urban Development, and SBTool. As SBTool consists of several modules, for comparability to other tools, a set of criteria and indicators used for the assessment in design stage is selected for the analysis. Along with these tools, which were all developed from developed nations, the Green Building Index for Township (GBI for Township), that was developed specifically for a developing country in tropical climate, Malaysia, is also considered for the comparative study. Even though the indicators of the selected tools encompass social, economic, and environmental aspects of sustainability, for the scope of this study, only those related to greenhouse gas emissions reduction and disaster resilience are analyzed.

### 3.1. Overview of the selected tools

#### 3.1.1. BREEAM-Community [63]

Developed in 2009 by Building Research Establishment Limited (BRE) in UK which has long experience in developing sustainability assessment tool for a building since 1990, BREEAM-Community

follows the same rating system, with focus on new development at neighborhood scale. Housing is considered in the scope of BREEAM-Community as this project type can convey significant impacts on transportation, land-use, social and economic characteristics of the existing communities. Apart from UK, several European and Middle-East countries have applied BREEAM schemes to certify their buildings [63].

#### 3.1.2. LEED-ND [64]

Under Leadership in Environmental and Energy Design (LEED) certification programs, LEED rating system have been developed for several categories to suit different building types. LEED-ND was launched in 2009 specifically for neighborhood development. It is developed under three main principles; smart growth, urbanism and green building with the emphasis on “elements that bring buildings and infrastructure together and relates the neighborhood to its local and regional landscape”. LEED schemes have been widely adopted to assess several types of buildings and projects in several countries in Asia, Europe, Middle-East, North-America and Latin America [64].

#### 3.1.3. CASBEE-UD [65]

With the intention to develop the assessment method for multiple buildings and other elements on a large-scale site, CASBEE-UD was devised by the Japan Sustainable Building Consortium (JSBC) in 2006. The tool was revised in 2007 to incorporate measures against global warming and the heat island effect.

#### 3.1.4. SBTool 2012 [66]

Similar to the other tools that began from the assessment of an individual building, SBTool 2012 was developed by the International Initiative for a Sustainable Built Environment (iiSBE), an international non-profit organization based in Canada, to cover larger scale development called as site assessment in the tool. Assessment schemes under SBTool has been applied in at least 20 countries in Europe, Africa, Canada and East Asia cited in [67]. Unlike other tools mentioned above, SBTool 2012 is designed for different development stages and local suitability, resulting in different sets of criteria and indicators. Users are able to select the development stage that matches their data availability. Also, they are required to assign weights for all assessment criteria before use. Although this process makes the tools more complicated than the others, it allows users to set their own priorities related to key concerns of their regions and countries [67].

#### 3.1.5. GBI for Township [68]

With the ambition to lead Malaysian building sector towards sustainable development, three versions of GBI were developed by Greenbuildingindex Sdn Bhd. for the assessment of new construction, existing building, and township. A township is defined as “a development of substantial size that contains a community or small neighborhood” [68]. The tool is designed for project assessment at the design stage.

## 3.2. General characteristics

Each of the rating tools discussed in Section 3.1 has core themes ranging from five to eight. Table 3 illustrates the core themes covering the three pillars of sustainability-environmental, social, and economic. To measure social sustainability, the existing tools focus on the common issues such as safety and well-being of the community residents, the availability of affordable housing and universal design for facilitate the use of diverse groups. Regarding economic sustainability, the assessment criteria often refer to employment opportunity or positive economic impact on

**Table 3**

Core themes and rating scales of five selected tools.

Tool	BREEAM-Community	LEED-ND	CASBEE-UD	SBTool2012	GBI for Township
Theme	1. Governance 2. Social and economic wellbeing 3. Resources and energy 4. Land use and ecology 5. Transport and movement 6. Innovation	1. Smart location and linkage 2. Neighborhood pattern and design 3. Green infrastructure and buildings 4. Innovation and design process 5. Regional priority	1. Natural environment 2. Serviced functions 3. Contribution to the local community 4. Environmental impact on microclimates, facade and landscape 5. Social infrastructure 6. Management of local environment	1. Site location, available services and site characteristics 2. Site regeneration and development, urban design and infrastructure 3. Energy and resource consumption 4. Environmental loadings 5. Indoor environmental quality 6. Service quality 7. Social, cultural and perceptual aspects 8. Cost and economic aspects	1. Climate, energy and water 2. Environment and ecology 3. Community planning and design 4. Transportation and connectivity 5. Building and resources 6. Business and innovation
Rating	Outstanding ( $\geq 85\%$ ) Excellent ( $\geq 70\%$ ) Very good ( $\geq 55\%$ ) Good ( $\geq 40\%$ ) Pass ( $\geq 25\%$ ) Unclassified ( $< 25\%$ )	Platinum (80–100) Gold (60–79) Silver (50–59) Certified (40–49)	Excellent ( $< 0.5$ ) Very good (0.5–1.0) Good (1.0–1.5) Fairly poor (1.5–3.0) Poor ( $\geq 3$ )	Best practice (5) Good practice (3) Minimum (0) Negative (-1)	Platinum ( $\geq 86\%$ ) Gold (76–85) Silver (66–75) Certified (50–65)

the neighborhood. It is obvious that most themes are dedicated to address environmental sustainability encompassing several issues related not only to energy and water consumption but also ecological value and indoor environmental qualities.

Each theme contains a set of indicators with a designated score. Such indicators are used to assess an urban project by determining the sustainability level and the scores are given according to the project's performances against the indicative levels. Then, the overall assessment result is calculated from individual scores through several techniques, such as, simple addition or weighting and addition. Finally, the overall result is classified into specific rating according to rating scale of each tool. The rating scales which are an interval scale, vary among different tools. LEED-ND, SBTool, and GBI have four rating scales while CASBEE-ND and BREEAM has five and six rating scales respectively. Different rating scales designed from different score interval reflect different requirement making it difficult to compare the assessment results among different tools [69]. Based on core themes of the selected tools, the issues of GHG emission reduction and disaster resilience are variably addressed as described in the subsequent section.

### 3.3. Coverage of indicators related to GHG emission reduction and disaster resilience

To gain understanding about how the actions aimed to reduce GHG emission and climate vulnerability is assessed, this study examined the selected tools according to their coverage and criteria weighting. Content analysis of the aim or intent of each criterion described in the manuals and guidelines of five tools was carried out to determine the indicators in two groups – GHG emission reduction and disaster resilience. The indicators that have intent to reduce energy use or GHG emission throughout the project lifecycle either in buildings-infrastructure, transportation, or waste management is classified in the first group of GHG emission reduction (hereafter GER). Those that aim to reduce climate-induced disasters risks (e.g., drought, flood, or earthquake) and indirect impacts of disasters including food and power outage are in another group of disaster resilience (hereafter DRL).

Some indicators are used to measure the practices related to GER and DRL. However, these indicators were not included in these two categories as their intents are for other purposes. For instance, provision of public open space is one of the indicators

that can be associated with the mitigation of heat island effect; nevertheless, this indicator is not included as its intent is for social benefits. Table 4 illustrates the sub-categories of both groups, number of indicators for each sub-category and percentages of indicators in each sub-category to the total indicators. The calculation of weighting is applicable only for four tools that have scores for each indicator. It is based on the sum of maximum score of the indicators falling under each sub-category relative to the total score. The analysis of the weighting can indicate the priority given to the subcategories of GER and DRL of each tool and different priority among five tools. In addition, GER to DRL ratios are determined from the sum of GER or DRL weighting divided by the total weighting of both categories.

Overall, GER and DRL are the main sustainability concerns for all of the tools, accounting for over half of the weighting. Among the five tools, LEED-ND places the greatest value on these two issues as indicated from 87% of the criteria related to both issues, followed by SBTool with 80.6% of the total criteria. The range of 52–69% criteria is found in BREEAM-Community, CASBEE-UD, and GBI for Township. There are more indicators related to GER. Building-infrastructure and transportation are the most important areas for GER in five tools. LEED-ND gives highest weightage for transportation, whereas BREEAM-Community and GBI for Township consider nearly equal importance between two areas. In contrast, CASBEE-UD and SBTool emphasizes more on building and infrastructure. The priority of waste management is placed after building-infrastructure and transportation for all tools. This corresponds to the proportion of global GHG emissions, of which 21% was generated from building and transport sectors and 3% from waste sector in 2004 [70]. The least weighting is found in the subcategory of efficient use of land. No interest in efficient land use is apparent for CASBEE-UD as the tool has no indicator for this issue. Since Japan has long recognized the effective use of land from its very high urban land use intensity, driven from land scarcity and high population [71], the efficient use of land is likely to be intrinsically realized during planning process without a need to have an indicator for measuring this issue.

For indicators related to sustainable transport, most of the tools give most importance to the proximity of the urban development project to facilities necessary for everyday-life. BREEAM-Community, on the other hand, places the highest value on creating walkable and cyclable environment. For criteria related to sustainable building and

**Table 4**

Summary of GER and DRL indicators in the five tools.

Category	Subcategory	Issues covered	BREEAM		LEED-ND		CASBEE-UD		SBTool2012		GBI for Township	
			No. of indicators (%)	Weightage	No. of indicators (%)	Weightage	No. of indicators (%)	Weightage	No. of indicators (%)	Weightage	No. of indicators (%)	Weightage
GER	<b>1.1 Building infrastructure</b>	<b>6 (15%)</b>	<b>18.1</b>		<b>12 (21.5%)</b>	<b>19</b>	<b>14 (33)</b>	<b>23</b>	<b>39 (14%)</b>	n/a	<b>10 (22.2%)</b>	<b>26</b>
	Heat island mitigation	Air movement/solar radiation/orientation	1 (2.5%)	1.8	1 (1.8%)	4	4 (9%)	9	5 (2.1%)		1 (2.2%)	4
		Shading by vegetation			1 (1.8%)		1 (2%)	1	2 (0.9%)		1 (2.2%)	3
		Exposed surface to sunlight			1 (1.8%)		3 (7%)	3	2 (0.9%)		1 (2.2%)	3
	Energy efficiency	Energy efficient buildings	2 (5%)	8.2	4 (7.1%)	10	1 (2%)	4	11 (4.7%)		1 (2.2%)	6
		Energy efficient infrastructure			2 (3.6%)		1 (2%)				1 (2.2%)	2
	Renewable energy		1 (2.5%)	2.7	1 (1.8%)	3	1 (2%)	2	3 (0.4%)		3 (6.7%)	8
	Reuse of existing buildings		1 (2.5%)	2.7	1 (1.8%)	1			2 (0.9%)			
	Low carbon materials	Reused/recycled materials	1 (2.5%)	2.7	1 (1.8%)	1	2 (5%)	1	1 (0.4%)		3 (6.7%)	3
	Energy management	Low embodied energy materials					1 (2%)	3				
DRL	<b>1.2 Waste management</b>	<b>1 (2.5%)</b>	<b>2.7</b>		<b>2 (3.6%)</b>	<b>3</b>	<b>6 (14%)</b>	<b>4</b>	<b>5 (2.1%)</b>		<b>4 (8.8%)</b>	<b>6</b>
	Construction waste		1 (2.5%)	2.7			1 (2%)	1			2 (4.4%)	2
	Solid waste	Facilities or programs to support waste reduce, reuse, and recycle			1 (1.8%)	1	3 (7%)	2	4 (1.7%)		1 (2.2%)	2
	Wastewater				1 (1.8%)	2	2 (5%)	1	1 (0.4%)		1 (2.2%)	2
DRL	<b>1.3 Efficient use of land</b>	<b>Compact/mixed use/infill/brownfield development</b>	<b>1 (2.5%)</b>	<b>2.1</b>	<b>5 (8.9%)</b>	<b>18</b>	–	–	<b>1 (0.4%)</b>		<b>2 (4.4%)</b>	<b>2</b>
	<b>1.4 Transportation</b>		<b>9 (22.5%)</b>	<b>19.9</b>	<b>14 (25%)</b>	<b>39</b>	<b>6 (14%)</b>	<b>5</b>	<b>14 (6.1%)</b>		<b>7 (15.5%)</b>	<b>27</b>
	Proximity to facilities		3 (7.5%)	6.6	6 (10.7%)	17	3 (7%)	3	7 (3.0%)		1 (2.2%)	13
	Walkability/cyclability		4 (10%)	8.5	5 (8.9%)	14	–	–	3 (1.3%)		2 (4.4%)	3
	Transportation planning	Demand management, community programs	2 (5%)	4.8	2 (3.6%)	7	3 (7%)	2	2 (0.9%)		1 (2.2%)	8
		Quality of public transport			1 (1.8%)	1			2 (0.9%)		3 (6.7%)	3
	<b>2.1 Water resource</b>		<b>2 (5%)</b>	<b>3.2</b>	<b>4 (7.2%)</b>	<b>6</b>	<b>4 (9%)</b>	<b>10</b>	<b>6 (2.5%)</b>		<b>2 (4.4%)</b>	<b>4</b>
	Water efficiency/saving		1 (2.5%)	2.1	3 (5.4%)	2	2 (5%)	5	5 (2.1%)		1 (2.2%)	2
	Storm water management	Low impact design	1 (2.5%)	1.1	1 (1.8%)	4	2 (5%)	5	1 (0.4%)		1 (2.2%)	2
	<b>2.2 Disaster planning</b>	<b>Consideration of risky zone, resilient building design</b>	<b>3 (7.5%)</b>	<b>6.3</b>	<b>2 (3.6%)</b>	<b>1</b>	<b>1 (2%)</b>	<b>1</b>	<b>1 (0.4%)</b>		<b>1 (2.2%)</b>	<b>1</b>
DRL	<b>2.3 Utility planning</b>	<b>Planning for emergency events</b>					<b>4 (9%)</b>	<b>7</b>	<b>3 (1.3%)</b>			
	<b>2.4 Food production</b>	<b>Community garden</b>			<b>1 (1.8%)</b>	<b>1</b>					<b>2 (4.4%)</b>	<b>3</b>
	<b>Total ratio of GER to DRL</b>		<b>22 (55%)</b>	<b>52.3 (82:18)</b>	<b>40 (71.6%)</b>	<b>87 (90:10)</b>	<b>35 (81%)</b>	<b>55 (67:33)</b>	<b>69 (80.6%)</b>		<b>28 (57.8%)</b>	<b>69 (88:12)</b>

infrastructure, energy efficiency has the highest weighting in BREEAM-Community, LEED-ND, and GBI for Township. The importance of site planning to mitigate heat island effect is highlighted in CASBEE-UD which contains eight indicators for this sub-category. Unlike other tools, SBTool 2012 has highest emphasis on low carbon materials.

Interestingly, not all sub-categories of DRL are included in the five tools. Only indicators involving water resource and disaster planning appear in all tools, but those related to utility planning and food production receive less interest. On water resource, although both water efficiency and stormwater management including run-off mitigation and rainwater harvesting are measured through various indicators, only LEED-ND and SBTool 2012 have indicators for measuring water conservation in landscaping. For disaster planning, flooding is the major concern in all tools except for CASBEE-UD which also focuses on earthquakes, the major disaster in Japan. Since natural disasters are country-specific, similar type of disasters is not applicable for all tools. This reflects the strong linkage to regions in the assessment tools for urban development [14]. To prevent disaster risks, land use planning takes a key role to ensure that no development occurs in high risk flood areas or minimal standards are met for the developments in less risky areas.

In line with land use planning, other indicators involved with evacuation route and the provision of shelters for disaster victims are found in CASBEE-UD. Disaster mitigation strategies can be classified in three stages: before, during, and after the disaster [72]. While other tools focus on anticipatory measure like land use planning, CASBEE-UD puts further emphasis on during-disaster activities that people immediately need when the disasters strike. Besides secure routes and places, CASBEE-UD adds more indicators related to infrastructure performance for supply not just in normal circumstances, but also in the event of a disaster [65]. Five indicators assess the reliability and flexibility of utility services including energy, water, sewerage and telecommunication. SBTool 2012 shares the same perspective on utility planning for emergency conditions. There are three indicators that can be used to measure the level of exposure in the event of an emergency evacuation situation, the number of days that basic utility services are provided, and the adaptive ability to change type of energy supply in future. In the literature on climate adaptation planning, redundancy and flexibility are the key principles for building a climate resilient community that has capacity to be functional even in unexpected situations [73–75]. In the context of disaster resilience, redundancy refers to the availability of multiple options such as backup system, a variety of routes for service delivery, or supply stocks, and flexibility refers to the ability to adjust to changing needs such as the shift from common ground to temporary shelter. The presence of indicators for measuring infrastructure performance in CASBEE-UD and SBTool 2012, therefore reflects the implication of such two principles of redundancy and flexibility in the sustainability assessment tools.

Food shortage is one of the indirect impacts of disasters. Only LEED-ND and GBI for Township have indicators related to food production. Three options are available in LEED-ND to assess the performance of local food production; the existence of community garden, the presence of community programs to support local agriculture, and the proximity to farmers' market. However, only one option of community garden is available in GBI for Township without specific requirement for minimal growing spaces, as indicated in LEED-ND. Despite the growing concern about potential effects of climate change on ambient temperature, water resource, and weather-related disasters, the incorporation of climate change information into sustainability assessment is still absent in most tools. Only BREEAM-Community has an indicator for measuring the level of adaptation to negative impacts of

climate change; however, those impacts are specified to rising temperature, water scarcity, flood risk, and changes in ground conditions and does not consider for food security.

### 3.4. Mandatory indicators

Except CASBEE-ND and GBI for Township, the remaining tools have mandatory indicators for different subcategories. This helps to guarantee that the minimum requirements in key issues are met for any project [76]. A variation in key issues across three tools is demonstrated in Table 5. Energy and water efficiency are the two subcategories that all the three tools agree for its importance and require to have mandatory indicators for guaranteeing the satisfied level of energy and water consumption. Only SBTool, however, emphasizes on the daylighting design, which is one of the passive design principles requiring low or no initial costs. Other issues considered as prerequisite requirement in at least two tools include reuse of existing buildings, efficient use of land, walkability, access to public transport, and planning with the consideration of flood risks. In addition, transport planning and evacuation planning associated with occupants' safety are seriously concerned in only one tool. It is to be noted that such mandatory requirements are related to environmental problems found in low income settlements such as remote settlement areas, inefficient use of energy, and disaster risks. Nevertheless, other issues including waste management and the scarcity of green open space are not considered as a prerequisite for sustainable development.

### 3.5. Assessment methods

#### 3.5.1. Assessment criteria

The assessment criteria of each indicator of all the five tools are well provided with explicit objectives, details and explanations. Table 6 summarizes all indicators in the categories of GER and DSL found in the five tools. It is observed that the assessment tools have the combination of qualitative and quantitative measures [15]. Qualitative indicators are largely found in the areas related to waste management, walkability, and disaster planning. When qualitative indicators are considered, specific requirements are clearly described to ensure that sufficient information is provided. For instance, the presence of waste facilities is the indicator for reducing the volume of waste deposited in landfills. In GBI for Township, to be awarded one point, two conditions are needed to be met. The first condition is the provision of recycling center with bins and truck access. The second condition is the presence of recycling initiatives supported by the local waste disposal company. To gain additional scores, two more conditions are needed to be met. Regarding quantitative indicators, precise numerical values are specified as indicative values to distinguish different performance levels such as the minimum percentage of water saving or the acceptable distance to urban amenities. As shown in Table 6, some indicators can be determined by using simple methods, such as, the evaluation on the presence of desirable feature or simple calculations. However, several indicators involve complex calculations or require technical studies as evidences for submission. Table 7 gives the example of documents required for the five tools. These documents undoubtedly need a team of experts from various fields of energy, transport planning, stormwater design, and disaster management, indicating the dependency on expert evaluation of the existing tools.

The expert-oriented approach is also clearly shown in the groups of user recommended in the tools' manuals as presented in Table 7. The main users are the developers and the professionals in the fields of architecture or urban planning, who can be considered as the experts. Although communities are mentioned

**Table 5**

Mandatory indicators of BREEAM-Community, LEED-ND, and SBTool 2012.

Category	Subcategory	BREEAM-Community	LEED-ND	SBTool 2012
GER	<b>1.1 Building infrastructure</b> Orientation, building layout Shading, outdoor surface Building energy efficiency	• Energy strategy	• Certified buildings • Minimum energy efficiency	• Consumption of non-renewable energy for all building operation • Appropriate daylighting in primary occupancy areas
	Renewable energy Reuse of existing buildings	• Assessment of potential use of the existing buildings		• Degree of reuse of suitable existing structures where available
	Low carbon materials Energy management			
	<b>1.2 Waste management</b> Construction waste Solid waste Wastewater			
	<b>1.3 Efficient use of land</b> Compact/mixed use/ infill development	• Investigation of contaminated land to determine the potential use of the land	• Compact development	
	<b>1.4 Transportation</b> Proximity to facilities Walkability/ cyclability	• Transport assessment with the consideration of street and cycle route design	• Walkable streets	
	Transport planning	• Travel plan, transport assessment		
	Public transport	• Provision of shelters at public transport stops	• Smart location with water and wastewater facilities and access to public transport	
DRL	<b>2.1 Water resource</b> Water efficiency/ saving	• Water consumption target	• Minimum water efficiency	• Use of water for occupant needs during operations
	Storm water management			
	<b>2.2 Disaster planning</b>	• Flood risk assessment	Avoidance of flood risky zones	
	<b>2.3 Utility planning</b>			• Egress from tall buildings under emergency conditions
	<b>2.4 Food production</b>			

as one of the tool users in BREEAM-Community and LEED-ND, many studies and reports required as the evidences are beyond the capacity of the communities to conduct or comprehend.

### 3.5.2. Requirement for national standards

In the selected tools for assessing sustainability in urban development, the assessment of environmental performance is largely based on national standards or regulations (Table 7), particularly in the sub-categories of energy efficiency and disaster planning. For example, the compliance to building certification systems of BREEAM and LEED is taken into account for scoring sustainable building practices. Likewise, the accordance with Malaysian guideline for flood mitigation measures is required in GBI for Township as well as the accordance with earthquake

resistance standard for the design of water supply and treatment systems in CASBEE-UD. Using national standards as the reference helps to reduce extensive information required to place on the indicators; however, desirable features or indicative values of such indicators are unknown. Unlike the other tools, SBTool 2012 does not rely on national standards as the tool was designed for universal use. Users are therefore able to fully understand the whole picture of a sustainable urban project featuring green components with specific requirements.

### 3.6. Affordability

Among the sustainability assessment tools except for CASBEE-UD, relevant indicators to affordable housing are indicated by the presence or percentage of affordable housing and are used for

**Table 6**  
GER and DRL indicators of five tools.

TOOL	BREEAM	LEED	CASBEE	SBTool	GBI
<b>1 Site plan to reduce UHI</b>					
1.1 Orientation	A study of microclimate	% of buildings with proper orientation (75%)	Form of building groups Measures to cope with strong wind Amount of sunlight exposed to public spaces	The angle of building axis to E–W (5–30°) % of buildings in adjacent site that will be shaded (35–0%)	Cross ventilation throughout the project (simulation)
1.2 Shaded area		% of shaded area by trees or structure (40%) or % of streets with trees (60%)	% of horizontal shade area % of green space	% of area shaded by tree (50–100%) LAI (0.3–1)	% of shaded pavement (50%) % of tree covers (20%)
1.3 Outdoor surface		% of roof with SRI > 29 (75%) or % of non-roof with SRI > 29 (50%)	% of paved area Presence of green roof % of green wall % of reflective wall Ratio of building height to site width to avoid wind blockage Spacing between building Continuous open space	% of landscaped area and high reflective surface (50–100%)	% of hardscape with SRI > 29 (50%)
<b>2 Building energy use</b>					
2.1 Building envelope	Use of best practice standards in sustainable design Rating level of certified buildings Presence of energy strategy to reduce carbon emissions	% of certified building	% of energy demand reduction (5%, 10%)	Predicted differential wind pressure in pascals (15–45 Pa) Air change rate during summer (0.5–1.0 ach) Air change rate during spring (0.8–1.5 ach) Air change rate during winter (0.4–0.8 ach) Air movement in conditioned area (0.2–0.8 m/s) % of air reaching work surface in conditioned area (30–50%) Compliance of mechanical system design to ASHRAE standard 55-1992	% of certified building
2.2 Renewable energy		% of onsite renewable energy generation (5–20%)	Use of renewable energy technologies (< 10%, > 10%)	Degree of structural adaptability for installing solar PV system	% of onsite energy generation (5–10%) % of renewable energy supply (5–20%)
2.3 Efficient energy use	Compliance with local lighting design % of street lighting efficiency	% of energy saving from street lighting (15%)		% of light lumen in an upward direction (2.5%) and the provision of automated daylight sensor controls Daylight factor of living area at ground floor (0.02–0.04 DF) Illumination level of 30–500 lux and the area interval provided with dimmable ballasts (15–10 m <sup>2</sup> ) Size of lighting system control zone (50–25 m <sup>2</sup> ) Separated thermostat for different functions	Compliance with local standards
2.4 Low carbon materials	Use of reused or recycled buildings/infrastructure/materials % of low impact materials used	% of recycled content in infrastructure (50%)	Use of recycled concrete (partial, full) Use of low carbon products (partial, full) Use of certified timber (partial, full)	% of building reused (10–30%) Weight of building materials per area (2500–1000 kg/m <sup>3</sup> ) % of non-renewable materials (80–30%)	% of recycled content in infrastructure (10%) % of recycled content in building structure (10%) % of regional materials manufactured

**Table 6** (continued)

TOOL	BREEAM	LEED	CASBEE	SBTool	GBI
<b>3 Waste management</b>					within 0.5 km (70%)
3.1 Modular design		Consideration for reducing construction wastes during design and construction stages (partial, full)		% of exposed floor, wall, ceiling (10–30%)	
3.2 Construction waste	Waste management plan		Presence of waste management activities e.g. sorting, recycling, reuse (partial, full)	Plan, center, disposal site	
		% of wastes diverted from landfill			
3.3 Solid waste		Presence of station, drop-off point	Presence of waste facilities	Provision of sorting facilities	Presence of station, drop-off point
			Category of waste sorted	No. of units with storage of solid waste and recycling (75–95%) Amount of liquid waste sent off from the site per year (0.35–0 m <sup>3</sup> /pp)	
<b>4 Land use efficiency</b>					
4.1 Previously used land	Use of previously developed land (75%)	% of the development on developed/infilled site (75%)			Location on developed site
4.2 Housing density		Number of units/acre		% of floor area complied with the standard (50–100%) No of land use (1 ≥ 3) Ratio of net functional area to occupied area (85–95%) Ratio of functional volume to occupied volume (85–95%)	% of density above standard
4.3 Open space			% of open space	Provision of open space (sufficient, convenient, comfortable)	% of open spaces (15%)  % of green space (+25% above standard)
<b>5 Transport planning</b>					
5.1 Walkability	Presence of transport assessment	Continuous sidewalks	Presence of cross circulation between vehicle and pedestrians	Quality of bike and walkway (bikelane, interval of connection with off-site bike path, shelter, distance to main building) Quality of walkway (% of access_10–20%, % of sheltered_25–50%)	Pedestrian network that is linked from hubs/shaded/safe
	Measures taken to create safe and appealing streets/walkways Design criteria for cycling network Provision of cycling storage	Bicycle network and storage			Provision of cycling network+storage
5.2 Access to facilities	No. of facilities located within walking distance (650 m for urban/1300 m for rural) Provision of utility services e.g., gas, electricity, water, telecommunication Distance to green space	Distance to parks (400 m) Distance to recreation facilities (400 m) Distance to school (1600 m) for 30% of units	Distance to supermarket (300–1500 m) Distance to bank Distance to local government's office Distance to hospital Distance to welfare facilities Distance to schools Distance to cultural facility		Existence of utility systems without extension  Distance to amenities (500 m)  Number of jobs/schools/amenities within 500 m
5.3 Access to public transport	Distance to transport node Provision of transport facilities	Frequency of transport trips Presence of transit station			Frequency of transport trips Presence of transit station/walkway within 500 m

**Table 6** (continued)

TOOL	BREEAM	LEED	CASBEE	SBTool	GBI
<b>6 Water management</b>					
6.1 Efficient use	Presence of water strategy	Use of efficient fixtures % of water saving (> 40%)		% of landscaped area with native species (50–100%) Amount of irrigation water (0.2–0.05 m <sup>3</sup> m <sup>2</sup> /year) Amount of water consumption (0.05–0.01 m <sup>3</sup> m <sup>2</sup> /year)	% of water saving (5–20%)
6.2 Reused water	*Included in the indicator of adapting to climate change	% of water saving for landscaping (> 50%) % of wastewater reused (25–50%)	Presence of water reuse system	% of units using gray water (25–100%)	% of wastewater reused (10–50%)
6.3 Rainwater harvest	*Included in the indicator of Adapting to climate change		Presence of rainwater storage (central/individual)		
6.4 Permeable surface	Peak rate of surface run-off	% of retaining stormwater on-site (80–95%)  % of hard surface designed for rainwater harvesting (> 5%)	% of area undertaken measures to reduce runoff (50%, > 50%)  % of stormwater treated by onsite system (25–100%)  Amount of retained water (standard or 300 m <sup>3</sup> /ha)	The ability of stormwater system to cope with 100 year flood events	% of decreased runoff (25%)
<b>7 Disaster planning</b>					
7.1 Risk zone	Flood risk assessment	Development on no/low risk zones or moderate zones with the compliance with local standards		Development on no/low risk zones or moderate zones with the compliance with local standards	
7.2 Building resilient design	Minimum floor level (0.60 m)/Under Adapting to climate change	Compliance with local standards			Compliance with local standards
7.3 Utility planning	Avoidance of risky area		Compliance of the design for water supply and treatment system with local standards Provision of common water supply for emergency Provision of common facilities for storing sewerage Provision of backup system		
7.4 Evacuation planning			Size of open space used as shelter Road width (8 m) and the number of exit (2) Distance to evacuation area		
7.5 Local food	Area for community garden/unit (5–20 m <sup>2</sup> /unit)	Area for community garden/unit (5–20 m <sup>2</sup> /unit)			
<b>8 Community participation</b>					
	Consideration of demographic needs and priorities	Community meeting	Participation in planning processes (no/some stages/all stages)		Address issues of existing communities
	Consultation plan with stakeholders/workshop organization	Community workshop			Presence of community center
	A panel set up to undertake a design review				
<b>9 Economic consideration</b>					
				Construction cost/m <sup>2</sup> (2000–1500 EUR) Operating cost/m <sup>2</sup> (200–100 EUR) Life cycle cost/m <sup>2</sup> (3000–2000 EUR)	

Note: Indicative values are indicated in bracket ( ).

**Table 7**

Characteristics of five tools.

Characteristics	BREEAM-C	LEED-ND	CASBEE	SBTool	GBI
Requirement for expert assessment	Microclimatic simulation Energy strategy Water consumption target and water strategy Flood risk assessment Transport assessment	Water consumption and saving Calculation of runoff volume and rate Energy model according to the LEED rating system and ENERGY STAR Calculation of stormwater retained on-site Annual energy consumption for infrastructure	Ratio of building elevation Building spacing ratio Calculation of sunlight provided to public spaces Calculation of reduced energy demand due to the use of clean energy sources	Calculation of indoor air flow rate Daylight factor and illumination level Weight of building materials Amount of liquid waste sent off from the site per year Ratio of net functional area to occupied area (85–95%)	Report on the onsite energy generation strategy Calculation of rainwater storage capacity Calculation of the volume of wastewater and reused water Report on flood risk assessment and mitigation Calculation of runoff volume and rate
	Calculation of the runoff volume and the peak rate of runoff Water consumption target and water strategy	Annual wastewater generated by the project		Amount of water consumption Volume of stormwater	Solid and construction waste management strategy
Dependency on local standards as the reference sources	Building rating tools such as the Code for Sustainable Homes and BREEAM	Building energy efficiency according to LEED scheme Water efficiency Flood zone map and local requirement for buildings construction in flood prone areas National baseline water usage for residential use	National standard for the design for water supply and treatment systems	Building rating tool by using GBI scheme Local guideline for stormwater management	Local standards for the design of road lighting Flood zone map and regulation for buildings in flood prone area Housing density guideline
Users	Developers, professionals, planners, politicians, and communities	Private developers, neighbors, citizens, and community	N/A	Owners, managers of large buildings	Project teams, owners, developers, and contractors

measuring social diversity of the development project. These indicators are not applicable in low income housing projects which require the consideration of household's financial capacity. Usually, household's expenditure on housing relative to household income is the key indicator used to measure affordability in various countries. According to the South Australian Department of Families and Communities, housing affordability refers to housing cost that does not exceed 30% of household gross income for a household that has the lowest 40% of incomes cited in [77]. Therefore, several assessment studies of low income housing have criteria to measure the percentage of rent or mortgage payment relative to household income. Other long-term costs associated with housing quality is also increasingly suggested to be incorporated into affordability assessment since household expenditure depend on various physical characteristics of housing such as distance to everyday facilities, energy performance of a dwelling, etc. [78]. The consideration of other costs related to life cycle energy consumption is clearly shown in the study of Portugal housing which includes operational and maintenance cost in the assessment [79].

### 3.7. Role of community participation in planning process

Compared with the assessment tools for urban development, the frameworks for low income housing have been developed mainly for post-occupancy assessment. Residents can engage in the assessment through the expression of their feelings on housing after the construction is completed. Physical characteristics that have poor performance are the target for improvements later. In contrast, the assessment tools for urban development are designed for the use in the design process. The role of local

communities in shaping the development before project construction is emphasized in all tools, except SBTool. This approach can minimize dissatisfaction on housing quality and prevent additional cost of the improvement. As Blair et al. [80] pointed out, careless initial design leads to the need for retrofits which are considered ineffective from sustainability point of view, and is usually more expensive. Also, community participation in the early stages can facilitate mutual communication about sustainable practices among stakeholders, providing better understanding about sustainable principles of housing design for low income residents. Among the existing tools, presence of activities such as the consideration of local needs, consultation, and workshop with stakeholders are indicators determining the extent of community involvement. In consideration of a ladder of citizen participation proposed by Arnstein [81], these indicators are designed to encourage the active role of communities in having the decision-making power during the planning process rather than being merely the passive informers or audiences. However, there are no indicators for measuring the quality of such participatory activities to ensure the effectiveness of participatory approach.

### 4. Limitation and improvement in the application of the assessment tools to low income housing in developing countries

According to the aforementioned characteristics of the existing tools, some limitations in applying the rating tools to low income housing in developing countries can be drawn and are discussed

below. Suggestions are also provided to improve the assessment tools for its use among non-expert group particularly low income residents in developing countries.

#### 4.1. Lack of concern on critical sustainability aspects

More comprehensiveness of DRL indicators is needed. Low concerns for disaster resilience of most tools can be explained due to very low risk of natural disasters as a result of high effective urban infrastructure for disaster mitigation in developed countries. However, low income housing in developing countries are more vulnerable to natural disasters. Insufficient disaster protection system and lack of institutional capacity in disaster management are the underlying cause of the risk of the population in developing countries to disasters [82–84]. Among several types of low income housing schemes, slum upgrading and self-help programs, which have been the important housing approach for developing countries where a number of informal settlements are concentrated [28,85,86], are in existing sites vulnerable to natural disasters. Some slum upgrading programs are situated at disaster prone locations, but close to locations of economic activities. Also, some are located in urban periphery that used to be agricultural land and prone to flooding. These low income housing are vulnerable to natural disasters. Considering the limited capacity to cope with disasters among the urban poor and more critical disaster events as a result of climate change, the integration of disaster resilience for low income housing development is imperative [12]. To be more comprehensive, disaster planning as well as utility planning for emergency events and local food production needs to be included. With regard to disaster planning, combined criteria from the selected tools are proposed for the assessment framework of low income housing. Considered as the low hanging fruit, disaster planning involves land use planning to avoid the settlement in risky areas and disaster assessment studies to provide better understanding about site conditions. Besides, it involves housing design to maximize safety during disaster incidences through structural resistance and the provision of evacuation routes and temporary shelters. For utility planning, criteria of these sub-categories are mostly adopted from CASBEE-UD which focuses on the reliability and flexibility of infrastructure services in communal facilities which are able to accommodate residents who suffer from power outage or non-functional toilets.

Regarding mandatory indicators, the existing tools put emphasis on some aspects of GER and DRL. They neglect some aspects which are associated with environmental problems found in low income housing in developing countries. Improper waste management and overcrowded conditions due to inadequate green open spaces are two major problems that can be overcome if the issues are viewed as the top priority during design stage. The provision of waste facilities and the ratio of open space should therefore be considered as mandatory for low income housing development. In addition, low cost measures which strongly influence energy and water efficiency should be marked as the mandatory requirements. Passive design involving building orientation, indoor ventilation and daylighting are feasible in the context of low cost housing as low to no investment cost are required for the implementation. Only daylighting design is found as the mandatory indicator in SBTool 2012. It is necessary to include other low cost measures in the mandatory scheme to raise awareness in passive principles for low income housing design.

#### 4.2. The dependency on expert evaluation and national standards

Several indicators of the selected tools for urban development substantially require the submission of technical studies, simulations, or complex calculations as evidences for the projects' performances.

It is apparent that this expert-oriented approach is time and resource intensive and this approach is not feasible for low income housing projects which usually have financial constraints. The evaluation of the City of Phoenix by using LEED-ND shows that significant attempts for data collection and labor works were required during the process and it was suggested to improve the rating system to reduce labor requirement to promote the application of LEED-ND in a wider scale [87]. Particularly in the case of low income housing, less dependence on expert evaluation is crucial to reduce costs during the housing design stage. Especially for the case of self-help programs, community residents with the assistance of community architects and professionals are the ones who develop their community's layout and house design [88]. It is therefore crucial to enable non-expert users, such as, low income residents to use the assessment tools for developing their own communities.

Among the selected tools for assessing sustainability in urban development, the assessment of environmental performance is largely based on local standards, particularly in the sub-categories of energy efficiency and disaster planning. Direct adoption of existing standards for use in other countries may not be appropriate. The adjustment of indicators is therefore required to make the assessment suitable to the local context, which are widely variable in terms of climatic conditions, technological availability, and building regulation. The core problem in most developing countries lies with the unavailability of building energy efficiency standard for residential buildings and local regulation for disaster risk mitigation. In 2009, only two developing countries in Sub-Saharan South Africa and South America have had energy standards for residential buildings [89]. In the Asia-Pacific region, although almost all countries have building codes, and not all building codes incorporate elements of environmental sustainability and disaster resilience, and not all codes are enforced strongly [90]. Baselines or benchmarks are thus needed to be set up in a number of countries that have no local energy standards. This process usually needs a fairly long timeframe as it involves the establishment of expert panel for determining baselines or benchmarks to develop criteria and indicators.

The use of practice or measure-based indicators can reduce the dependency on expert evaluation and it is useful for the countries where national standards for energy-water efficiency and disaster planning do not exist. According to ISO [91], there are two types of environmental performance indicators (EPIs) – Management Performance Indicators (MPIs) and Operational Performance Indicators (OPIs). Unlike OPIs which provide information on the environmental performance of the project's operations, MPIs are evaluated on the basis of management efforts to influence the environmental performance of the project's operations. Instead of using performance-based indicators or OPIs that usually require complex calculations for determining the project's performances, measure based indicator or EPIs are based on the adoption of green practices proposed for particular issues. These measure-based indicators can also be used as design guidelines for low income residents.

#### 4.3. Purposes of the assessment framework

The assessment tools for urban development were designed to be applicable to a range of development types including housing development. Among the five tools, however, only SBTool has the option for the assessment of residential development, classified as attached housing or apartments. This option leads to a set of benchmarks specific for residential purposes. LEED-ND also considers the differences between residential and non-residential development through indicators, such as the project's density, parking spaces, and energy and water efficiency requirements. However, some aspects are beyond the community's capacity to handle and also depends on other factors. According to the evaluation of Westlawn Gardens in Milwaukee by Global Green,

several issues cannot be achieved due to the lack of regulatory support, such as transit accessibility and reduced car park footprint [92]. Also, LEED-ND includes some indicators which are not related to housing development, but are included to make the tools more general, such as, indicators dedicated to create walkable streets with relatively high credit. Such indicators are suitable for the mixed use development comprising commercial stripe but not for a project with 100% residential development. With new urbanism design promoting mixed use development, a combination of housing units with commercial, residential, educational, and cultural amenities has been adopted in developed countries. The rating tools are thus applicable for such countries. Although the concept of mixed use development has been promoted in many developing countries [93,94], its implementation is still limited for only showcase projects such as ECO CITY in Malaysia and Suzhou mixed use development in China. Options specifically for low-rise and high-rise multifamily housing should thus be provided by the assessment tools.

#### 4.4. Lack of financial consideration related to building life cycle and natural disasters

Since affordability is fundamental to all low income housing developments, the consideration of financial aspects is important for project evaluation. Sustainable assessment tools do not take into account financial viability of a project, leading to costly developments that are potentially unattractive from the perspective of developers [69,95]. The lack of financial concerns partly contributes to the exclusion of green practices from a range of projects serving such low income housing. The integration of project cost encompassing land acquisition and construction cost into building assessment tools is therefore suggested, bringing the tools into closer alignment with actual practices where cost-benefit analysis is employed to compare and rank project alternatives before a decision is made [69]. Among the five studied tools for urban development, only SBTool 2012 includes criteria related to financial aspect in the assessment including development cost, maintenance cost, and life-cycle cost. Compared with existing assessment framework for low income housing, affordability mainly lies on rent or mortgage payment that hinges on initial costs of project development [77,78,80]. Operational or post-occupancy costs are often taken account through building energy efficiency and the distance to everyday facilities/amenities. However, building maintenance and life cycle costs are not included. Household expenses related to disaster prevention and recovery is also not mentioned. It is noted that risk and loss financing is usually not integrated into housing finance mechanisms despite significant amount of low income household expenses for disaster risk reduction ranging from at least 9.2% of total income in El Salvador to 25% in risk-prone area in India [96]. Evidences show that some slum communities in Asia use saving mechanisms to assist households to repair their property or assets in emergency cases including disaster events cited in [96]. The role of micro-insurance as a means of protecting the poor against losses caused by severe natural disaster has also been increasingly realized and there are calls for such financial schemes to reach the urban poor [97,98]. Besides initial costs, sustainable assessment framework should thus place emphasis on building life-cycle costs, and disaster risk and loss financing.

#### 4.5. Community participation

Community participation is widely accepted as the key mechanism for low income housing projects in developing countries [99], as it is a means to achieve better project results and consequently better housing conditions for the community [100]. The role of local

communities in shaping the development before project construction is emphasized in all tools, except SBTool. In BREEAM-Community, there is mandatory requirement for the establishment of consultation group consisting of community members and appropriate stakeholders. To obtain a score in several categories, a consultation plan that reflects local community's needs and priority needs to be considered and influences the decision for the project's layout, density, facilities and amenities, and housing type. As all these physical characteristics affect energy consumption and vulnerability to natural disasters, local voices are therefore very influential in shaping their community towards low carbon and disaster resilient pathways. It is to be noted that not only participatory activities should be taken into account, but the quality of participation in terms of representativeness and the collaboration with external agencies should also be considered. As a majority representation on the decision-making board is denoted as the highest mode of participation [101], representativeness of the community will ensure that participatory process delivers both diverse and inclusive information.

As demonstrated above, the rating tools have limitations on the application to low income housing in developing countries as the tools substantially rely on local standards, expert evaluation and lack of inclusion of key aspects, especially disaster resilience and financial. In addition, the comprehensiveness of the tools for different types of buildings makes the assessment for residential projects cumbersome. These shortcomings prevent the application of the rating tools in developing countries along with the absence of building regulations for energy-water efficiency and disaster planning. Also, the rating systems are not suitable for general urban projects with limited budget like low income housing due to the great demand for multidisciplinary expert evaluations. Only subsidized or pilot projects are applicable but scaling-up the application will be potentially problematic. Considering the speed of the construction of low cost housing in developing countries today, the gaps of the existing assessment framework are urgently needed to be overcome.

## 5. Conclusion

To address the housing crisis and the prevalence of informal settlements in developing countries, several approaches including public housing, incremental development, and market-based housing have been simultaneously implemented to facilitate the urban poor in having better access to land and shelter. With growing concerns on resource depletion and adverse consequences of climate change, several environmental issues, such as increase in GHG emission and disaster vulnerability are found in low income housing schemes. To determine the effectiveness of the existing sustainability assessment frameworks for low income housing in addressing the issues of GHG emission reduction and disaster resilience, this paper reviewed five sustainability assessment tools for urban development to find their limitations in the application of the existing tools to low income housing in developing countries. Based on the analysis of the selected tools, four major limitations were identified: lack of key sustainability issues related to disaster resilience and low cost measures, dependency on expert evaluation hampering the use of rating tools among non-expert groups, exclusion of financial consideration and lack of focus on some aspects of community participation. To address these limitations, and to make those assessment tools should more comprehensive, environmental issues of low income housing and financial concerns should be considered as the priority. The assessment methods of the tools should also be simple, allowing low income residents to apply the tools during their housing planning with a cost effective and timely manner. With such improvements,

more comprehensive and inclusive environmental sustainability assessment framework can be developed to build low carbon and climate resilient low income housing settlements. Studies on the development of the environmental assessment framework comprising specific indicators for self-help housing projects located in developing countries as well as the verification of the developed assessment framework will be needed.

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